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Building Codes, Energy, and the Environment

How Model Building Codes Affect Sustainability

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Foreword

This study was conducted for Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project AT45, "Energy Technologies Applied to Military Facilities"; Work Unit X09, "Installation Strategic Energy Planning: Sustainable Design." The technical monitor was Joe McCarty, CECW-ED.

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1 Introduction

Background

The built environment has a significant impact on available natural resources. According to the World Watch Institute, the building construction industry consumes 40 percent of the raw stone, gravel, and sand marketed. Additionally, 25 percent of the virgin timber used globally each year goes into the construction and remodeling of buildings (Roodman and Lenssen 1995). In the United States, buildings consume 31 percent of the total energy expended each year. Approximately 50 percent of the SO_2, 25 percent of the NO_x, and 35 percent of the CO_2 produced are attributable to building energy consumption. This translates into about $210 billion per year for energy use in buildings ($120 billion for residences and $90 billion for nonresidential buildings). Twenty-eight percent of these buildings are publicly held and 78 percent of the buildings are held in private ownership (Kats et al. 1996). This means that the overwhelming amount of building energy and building energy-related expenditures are applied to privately owned properties. Attempts to minimize building energy expenditures and their coincidental environmental impacts must therefore focus on the private sector and on the mechanisms for their regulation that are currently in place.

The principal vehicle for the regulation of private building and construction practices is building codes and standards. Before WWII, the promulgation of codes and standards was the responsibility of local jurisdictions, typically municipalities. The only nationally scoped codes were those developed by insurance companies (the original National Code) and those used for implementation of Federal programs such as the Federal Home Administration (FHA) and the Housing and Home Finance Agency (HHFA). The purpose of these documents was primarily to ensure public health and safety. They typically addressed structural sufficiency, fire protection, and plumbing requirements. Code organizations such as the International Conference of Building Officials (ICBO) and the Building Officials and Code Administrators International (BOCA) allowed the comparison of code requirements beginning in the 1920s, but it was not until after WWII that those organizations published the first model building codes for widespread use (Rose and Deal 1998). These initial forays into model building

codes contained many provisions borrowed directly from the documents of the FHA and HHFA.

The vision of consistency and predictability in building construction standards has been partially impaired over time due to home rule powers. The system's evolution has left the responsibility of selecting and adopting the allowable minimum building codes to individual States. State governments however, typically have no responsibility for the administration and enforcement of those codes. Those functions are left to the discretion of local, home rule governments (including local school boards and other State agencies). As a result of this local discretion, today's "system" is a patchwork of codes and regulations developed, amended, administered, and enforced differently by numerous local jurisdictions and State agencies, none of which are focused or expert in techniques of sustainability, or the conservation of energy or natural resources. What is needed is a general set of codes that focus not only on occupant safety, but life cycle costs of structures as those costs relate to energy use and the environment.

Objective

The objectives of this study were to summarize the current status of national building codes and standards relative to energy efficiency and environmental competency, and to identify ways in which those codes and standards could be changed to reduce energy consumption and negative effects on the environment.

Approach

This research began with a study of the literature on building codes, building standards, and sustainable systems. Model building codes were identified and discussed from a historic and present day perspective. Once the current state of the system was determined, the codes were then reviewed for content related to prescriptions on energy conservation and environmental sustainability. Within this report, a discussion on performance based codes (Chapter 4) follows and leads to a discussion relating to possible code improvements and suggestions relating to how these documents can be modified to meet the present national agenda for highly efficient buildings (Chapter 5). A general discussion on improving the sustainability of the built environment through the use of model codes and standards concludes the report.

This research also developed environmental impacts relating to specific materials. Note that this document was not part of the original scope of this study; they are presented here as an appendix to this report.

Scope

This report defines the current state of model building codes as they relate to issues of energy conservation and sustainability. The recommendations contained in this report can help foster continued discussion on improvement of the model codes and toward a more sustainable built environment.

Mode of Tech Transfer

Information from this study will be published in the Public Works Digest and disseminated through Energy Awareness and Energy Managers conferences and seminars. It will also be included in conferences relating to issues of sustainable built systems.

2 Model Codes

Model building codes represent an effort by public sector code enforcement officials to provide a comprehensive regulatory document to guide decisions within the built environment. A regulatory community adopts a model building code into law to establish minimum acceptable standards necessary to protect the health, safety, and welfare of its constituents. Building codes and standards are the technical codifying of community decisions that satisfy human needs while improving and maintaining the quality of the built environment. The primary application of building codes is the regulation of new or proposed construction. Building code requirements typically apply to existing buildings only when the building is undergoing reconstruction, rehabilitation, alterations, or when the nature of the building occupancy has been changed. Currently, three model code organizations in the United States promulgate building codes for adoption, and two others (the International Code Council [ICC] and the Council of American Building Officials [CABO]) are a collaboration of the code bodies aimed at unifying practices:

- The Standard Building Code, published by Southern Building Code Congress International (SBCCI), is typically used throughout the southeastern United States.
- The National Building Code, published by BOCA, is typically used throughout the northeast and central States.
- The Uniform Building Code, published by International Conference of Building Officials (ICBO), is typically used throughout the west.
- The International Code Council (ICC) was established as a nonprofit organization dedicated to developing a single set of comprehensive and coordinated national codes.
- The one and two-family dwelling code (1995) was established by the CABO.

Figure 1 shows the geographic distribution of current model building codes. These codes are based on the sound principles of safety and recognize the differences between standards and regulations. However, these codes contain only the necessary requirements to provide for the safety of the occupants of buildings and their neighbors. They are intended to provide for the general communal good rather than to protect individual or environmental interest.

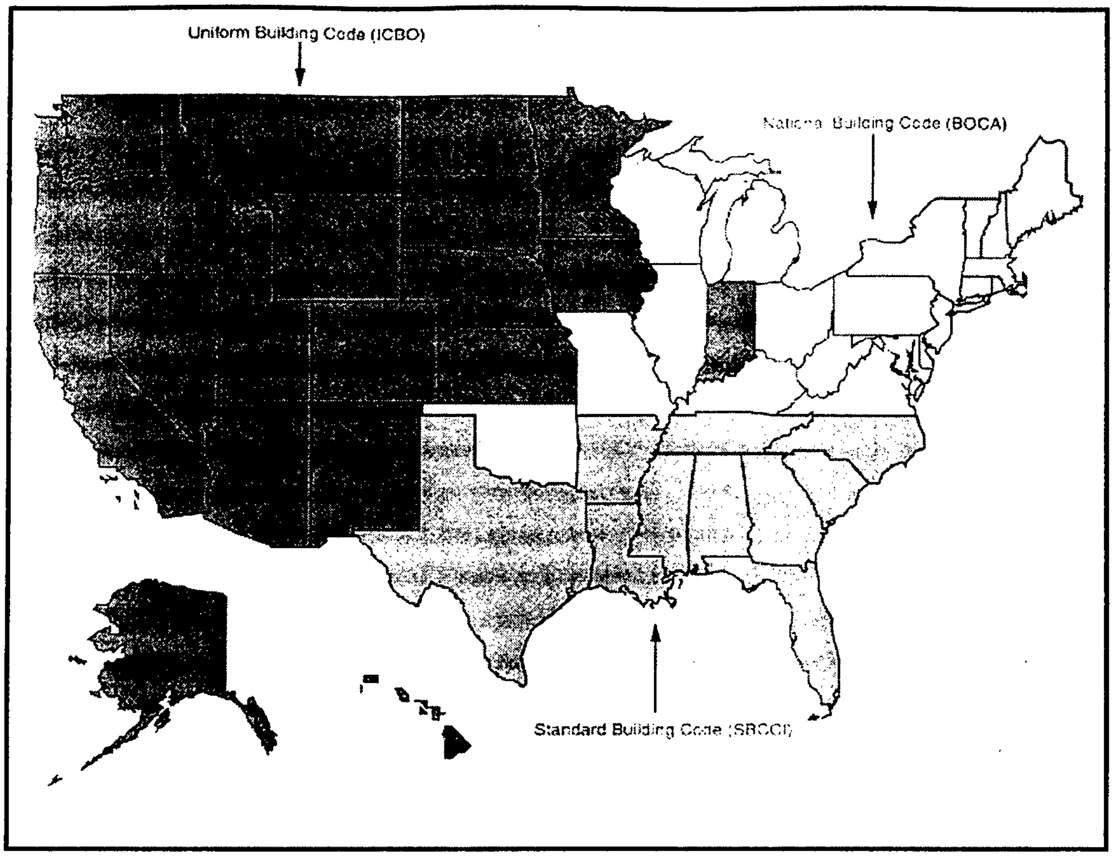

Figure 1. U.S. geographic distribution of current model building codes.

Two additional codes deserve mention before a more detailed discussion of the model codes can be considered. These codes relate more specifically to energy and resource conservation issues and are sometimes referred to in the model standards. The first is the Model Energy Code (MEC), published by the CABO. The MEC applies to both residential and nonresidential buildings. The second are the Energy Codes published by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE); Standard 90.1 - Energy Codes for Buildings, Except Low-Rise Residential and Standard 90.2 - Energy Efficient Design of New Low-Rise Residential Buildings. These will be more rigorously discussed later in this report.

The BOCA National Building Code 1996

The National Building Code of BOCA is a model that is meant to apply to all building types and covers the construction, alteration, repair, removal, demolition, use, location occupancy, and maintenance of all existing or proposed buildings and structures. The code provides minimum standards to ensure the public safety, health, and welfare insofar as they are affected by building construction

and to secure safety to life and property from all hazards incident to the occupancy of buildings, structures, and premises. The 1996 BOCA code refers to the 1995 MEC for energy conservation, but has no other supporting or regulatory documentation and no backup of the MEC provisions. It also makes no reference to construction waste, or any other environmentally related issues.

In the 1993 version of the code, Article 31 regulates the design and construction of the exterior envelope and the selection of HVAC, service water heating, electrical distribution, and illuminating systems. It also encourages usage of renewable (nondepletable) sources of energy by stating that, where alternative systems use solar, geothermal, wind, or other nondepletable energy sources for all or part of the system's energy sources, such energy supplied to the building shall be excluded from the total energy chargeable to the proposed alternative design. This version requires conformance to the energy conservation section (Chapter 13). Compliance with 1995 MEC is noted to be an alternative.

The code requires that plans and specifications be sufficient to determine compliance with the code. In general, the code takes a "minimum standards" approach; it does not prevent quality construction or resource efficiency, but it does not encourage or prescribe their inclusion.

The SBCCI Standard Building Code 1997

The SBCCI Standard Building Code of 1997 is a model that is meant to apply to all building types and to guide decisions aimed at protecting the public's life, health, and welfare in the built environment. It professes to provide a high degree of flexibility through some very marginal performance-based provisions. It covers the construction, alteration, repair, removal, demolition, use, location, occupancy, and maintenance of all existing or proposed buildings and structures. The criteria are mostly associated with structural issues, waterproofing, vermin proofing, fire proofing, and general safety issues.

The SBCCI model code does not have any pages devoted to environmental issues. The code refers to the 1995 MEC for energy conservation, more specifically ASHRAE 90.1 for commercial buildings or ASHRAE 90.2 for residential buildings (three stories or less). The SBCCI code also states that these provisions must be specifically adopted. The rest of the chapters and appendices are virtually silent on the issue of energy or the environment. The SBCCI code is similar to the BOCA code in that it takes a "minimum standards" approach.

The 1991 version of this code included a two-page appendix devoted to energy conservation. The provisions of the appendix regulate the design of building envelopes for adequate thermal resistance and low air leakage, and the design and selection of low-energy mechanical, electrical, and illumination systems. Compliance with ASHRAE Standard 90.1 is deemed to meet energy-related requirements. These provisions are missing from the current edition.

The ICBO Uniform Building Code 1997

The ICBO Uniform Building Code of 1997 is dedicated to the development of better building construction and greater safety to the public by promoting uniformity in building laws. The provisions of the code are divided into three volumes. The first volume accommodates administrative, fire and life safety, and field inspection provisions. Volume two contains structural engineering design provisions and volume three deals with material, testing, and installation standards. The code covers construction, alteration, repair, removal, demolition, use, location, occupancy, and maintenance of all existing or proposed buildings and structures.

The code refers to the 1995 MEC for energy conservation. It also states that these provisions must be specifically adopted. There are no other references to issues of energy or environmental protection. ICBO does require that plans and specifications be sufficient to determine compliance with the MEC code, which makes the ICBO code an improvement over the other models.

One- and Two-Family Dwelling Code, 1995, Council of American Building Officials (CABO)

The CABO One and Two Family Dwelling Code of 1995 is an expanded residential building code. It is one of the first codes intended for nation-wide adoption, and to represent the three major model code developing organizations. Its purpose is to provide minimum requirements to safeguard life, health, and public welfare, and to protect property. It relates to the design, construction, prefabrication, equipment or appliance installation, quality of materials, use and occupancy, location, and repair of detached one- and two-family dwellings less than three stories in height. It is a synthesis of material from 12 other codes (three model building codes, three model plumbing codes, five model mechanical codes, and the National Electric Code [NEC]). The code addresses traditional residential construction materials and practices and is prescriptive in nature. Alternatives are not specifically addressed in the code. Energy conservation in new

building design and construction refers to the 1995 MEC, but the provisions for energy conservation are enforceable only when specifically adopted by the jurisdiction.

Much like the codes already discussed, this model building code makes no mention of environmental issues associated with material selection or waste generation during (or after) construction. All mention of energy is confined to a few sentences referring to the MEC.

Generally, a building code can be viewed as a legal instrument that has been put in place by a State or local government to protect the general welfare of its citizens. The provisions of the code in place must be adhered to if a building is to be considered in conformance with the law and suitable for occupancy and use in that jurisdiction. Building codes have historically been concerned only with a narrow view of public safety as it relates to structural conformance and immediate bodily harm during the construction of a building. Long-term impacts of buildings and building construction have been noticeably absent from the model code literature.

3 Energy and Resource Conservation Codes

The purpose of regulatory building codes is not always clearly defined. Control over siting, design, or construction methodologies may have more than one purpose. Typically the intent is to protect the public from danger, prevent injuries, and generally safeguard the health and well being of those who live or work in or near the facility. It is also possible for regulatory codes to promote the economy of environmental resources, or to protect consumer investment (Sanderson 1969).

Traditional building construction and code enforcement practices often overlook the intricate relationships between a building, its surroundings, and its occupants. Too often they focus on prescriptive solutions. That is, they require strict execution of the precise terms in the code requirements (subject to enforcement interpretation). Prescriptive building codes do provide some significant benefits:

- compliance is simple
- enforcement is simple, since the compliance criteria are visible and readily measurable
- the criteria for product development to support the requirement are simple.

What prescriptive building codes do not provide is a sensitivity to the outcome or performance of the prescribed assemblies or the impacts of the prescriptions on environmental or socially related systems. Since compliance and enforcement are so easily regulated and defined, prescriptive standards have been the code of choice to date (by both the development and regulatory communities). Current prescriptive energy standards are most prominently found and referred to in ASHRAE/IESNA Standard 90.1 and the MEC.

ASHRAE Standard 90.1

ASHRAE Standards 90.1 and 90.2 serve as model codes for commercial and residential buildings. The standards are produced by two professional organizations, the American Society for Heating, Refrigerating, and Air-Conditioning Engineers, and the Illumination Engineering Society of North America. These standards are somewhat redundant with the model codes and in general are no

stricter in terms of conservation than the other model codes. However, note that the intent of the standards is to meet environmental conditioning issues associated with HVAC and lighting systems. The standards provide guidance for adequate conditioning and lighting within a minimum energy framework. They also offer a framework for assessing building design and determining compliance. Standards 90.1 and 90.2 are more consensus standards driven by the private building industry, which means that compliance is relatively simple and that targets for equipment efficiencies are essentially the minimum that available equipment provides. ASHRAE does acknowledge that more efficient designs can reduce the energy used to heat, cool, and illuminate by as much as 40 percent, but those efficiencies are not required in the standard framework.

ASHRAE includes a policy statement for the environmental impact of member activities, which encourages ASHRAE's members to:

> Strive to minimize any possible deleterious effects on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted standards and the practical state of the art.

ASHRAE also seeks to take the lead in the dissemination of pertinent environmental information and will seek out information from other responsible organizations. The environmental policy statement also implies that the disposal of hazardous materials should be considered during the design process. They also mention the possible environmental impacts due to the energy source and transportation type, but give this little supporting documentation for calculation and practical use.

ASHRAE offers a two-path compliance methodology. The first is the Systems and Components Method. It is a combination of prescriptive criteria for each building component with some performance criteria for specific subsystems (e.g., lighting). As a prescriptive criteria, it is simple to engineer and regulate. Evaluation and compliance are easy to ascertain.

The second compliance path is the Building Energy Cost Budget Method. This requires the design to have an overall energy budget cost that is equal to or less than an energy budget cost for a prototype or reference building (similar to the MEC). This system requires sophisticated energy modeling tools and analysis, but has the potential for a more rigorous, performance-based compliance outcome. The intent of the Building Energy Cost Budget Method is to provide flexibility in compliance with energy standards by allowing differing approaches to conservation. It allows a building designer to evaluate innovative energy con-

servation methodologies and approaches that the Systems and Components Method (e.g., daylighting, passive solar heating, heat recovery, zonal control, and thermal storage) cannot account for. This methodology can also be used to compare competitive design options.

Standards 90.1 and 90.2 are comprehensive and complex. They represent a valid framework and methodology for designing and evaluating buildings for energy performance criteria. Stiffer prescriptive standards and more rigorous performance-based approaches will enhance the general framework of the standards.

The CABO Model Energy Code

The MEC is promulgated jointly by BOCA, ICBO, and SBCCI under the auspices of the CABO. MEC is updated annually and republished every 3 years. The code spells out the design conditions for analysis and sizing of equipment. For residential buildings, compliance to the code is determined in three ways: a systems approach for the entire building and its energy-using subsystems (which may include renewable sources), a component performance approach for various building elements and mechanical systems and components, or specified acceptable practice. For buildings other than residential, the code defines a prescriptive system, or energy cost budget approach. The MEC's major focus is on building envelope insulation, including the windows. The MEC requires insulation on ceilings, walls (including basement walls), and floors, and around slabs. The amount of insulation required varies with the climate. (The more severe the climate, the more insulation is required.) Window energy efficiency requirements also increase with severity of climate. "A Climate-Specific Code" shows some sample insulation and window levels that meet the MEC requirements. The thrust is on regulation of the exterior envelope, and on selection of the HVAC, service water heating, electrical distribution and illumination systems, and equipment for effective use of energy.

All of the insulation and window requirements in the MEC can be traded off (varied), so long as the resulting building does not have a greater average heat loss (conductivity [U] x area [A], or UA)* than a similar building constructed to meet the MEC requirements. For example, ceiling insulation exceeding the

* Dimensions of U are expressed in Btu/sq-ft °F; dimensions of A are expressed in sq ft (1 sq ft = 0.093 m^2).

MEC-required level can be traded off against less floor insulation than is required. Several compliance options can be used to demonstrate such trade-offs. For instance, a builder accustomed to using 2 x 6 wall construction can get relatively high wall R-values that can be traded off against lower insulation levels in the basement or a larger window area. (The MEC has no inherent limit on window area.) Simplified software products that allow trade-offs and demonstrate compliance may offer the best combination of simplicity and flexibility.

A whole-building energy analysis can be used to show energy use equal to that of an MEC-compliant home; however, this approach is complex and is seldom used. It requires that the building be similar to the code compliant structure with the same energy source(s), equal floor area and the same ratio of thermal envelope area to floor area, similar exterior design, similar occupancy, and locational climate data, and the compared structures should have similar uses and operational schedules. Basic criteria must also be met regardless of which envelope compliance approach is used:

- sealing the building envelope to restrict air leakage (caulking, sealing, and weather-stripping at all penetrations and joints)
- installing vapor retarders in most climates
- identifying materials used for compliance (such as insulation R-values) on plans, specifications, and/or directly on materials in the residence
- installing temperature controls (separate adjustable controls for each HVAC system in single-family homes and for each multifamily dwelling unit)
- insulating and sealing ducts in unconditioned spaces
- insulating pipes for hydronic heating and circulating hot water systems
- installing separate electric meters for each unit in a multifamily dwelling
- installing heater switches, covers, and time clocks for swimming pools.

A standard set of criteria for the component energy performance approach does exist. If the criteria are met, then the energy analysis requirement is waived.

The MEC provides for alternative conservation measures assuming that (or as long as) energy consumption patterns are not increased. This addresses renewable energy systems and allows for their energy production to be excluded from the total energy chargeable to the design. This does not prevent poor standard performance, since deficiencies can be made up with the inclusion of renewables. Consequently, the addition of renewable resources can in some cases decrease standard design efficiencies. (This is not a good provision.)

Note that performance-based code requirements contrast to strict prescriptive requirements or component approaches. Performance requirements direct only

that the end result be defined; the means to achieve that end need not be explicit. Although performance-based requirements lack most of the benefits of a prescriptive requirement (e.g., ease of enforcement and compliance), they compensate with one substantial benefit—they intend and promise that the end product will perform according to the desired criteria.

4 Performance-Based Codes

Performance-Based Building Codes

Prescriptive building codes have been described to provide "the worst building that can be built without going to jail." Although somewhat overstated, this view highlights the fact that many building and design professionals believe that prescriptive building codes are restrictive and that they inhibit creative solutions. Many design professionals resort to the catch-all phrase "as per local codes and ordinances" to keep from having to rewrite the prescriptive verbiage and to avoid local code enforcement variability. Historically, the prescriptive regulatory method gave the builders and design professionals no special problems because local materials and traditional craftsmen and construction technologies were well established, well known, and well practiced. Post War mechanization, mass transportation, the development of new materials, production methods, and non-traditional calculation techniques have made it increasingly difficult to rely on prescriptive regulatory methodologies.

The idea of performance-based building laws has a long history. The Code of Hammurabi* (2nd century BC), once considered the oldest promulgation of laws in human history, included stipulations that the builder of a building was responsible for its structural integrity. The Roman architect and engineer Vitruvius (1st century BC) included performance as well as prescriptive-based design requirements in the *De Architectura Libri Decem* (Ten Books on Architecture). More recently, the National Bureau of Standards recommended the use of performance-based codes to "allow the use of new and creative materials" in 1925. The first international conference on performance based codes was held in Philadelphia in 1972, with follow up discussions in 1982 and 1996. Current model building codes "permit" some performance-based standards, but "do not overly encourage it." The National Institute of Standards and Technology (NIST) is

* Ruler of the 1st (Amorite) dynasty of Babylon (reigning c. 1792-50 BC).

currently putting together performance-based standards for Federal government construction projects.

One advantage of a performance-based approach is the codification of the rationale behind the given requirements. This provides a logical basis for building regulations that does not explicitly restrict the designer on the choice of materials or their arrangements. This approach encourages research and development in the building sciences by inviting new and innovative solutions to user needs. Performance can be defined as both "behavior in use" of a building, or as "a measure of the effectiveness of the outcome of a system." That implies that the performance-based approach is also concerned about the operational efficiency of a building.

The performance codes that are being proposed in the United States contain a judicious combination of standard specifications and performance requirements. Although these codes establish performance requirements, the quality of the materials selected and the manner in which they are used are governed by material standards and accepted engineering design criteria. Although performance is suggested as the basis for design, an assembly can still be prescriptive in nature. Prescriptive standards typically apply to individual components of a system; a performance standard considers the system as a whole. In a sense, prescriptive standards may be viewed as performance standards for individual components. Still, performance guidelines and prescriptive guidelines may, at times, be in conflict.

An important component to performance-based methodologies is the ability to encourage design for permanence. Current prescriptive standards allow for minimal building life expectancy. This minimum standards approach along with current tax laws that favor the quick depreciation of assets, encourage a "first cost" basis for decisionmaking. Performance-based standards can help to promote a life cycle project assessment that takes into consideration building energy, operational expenses, and the expected life of the building and its components.

Performance-based building methods also increase the likelihood of designing for permanence by providing a basis for performance-driven fee structures. Current percentage-based building fee structures rewards the building team for using the most expensive, easiest to implement building systems. (This typically means oversized and inefficient systems.) There are no long-term rewards for a well built, permanent structure that is operationally efficient. In a performance-based fee structure, the building team would benefit the most by designing cost effective and operationally efficient systems. Rewards in the form of higher fees

would be given on the basis of over-all building efficiency, environmental viability, and life-cycle returns, not on the basis of first costs.

Codes and fee structures based on building performance would be more difficult to assess and enforce, however. Proof of inadequate design or poor construction methods would be difficult to assess and would depend on simulation models and hypothetical calculations (Weber 1998). Complex building systems composed of many different materials with very specialized functions, may increase the systems vulnerability and its liability to fail (CIB 1983). Performance-based standards also increase the liability for the designer and rely on improved skills of code enforcement officials. This increases the complexity of code enforcement and implementation. These problems are not insurmountable. The move toward performance-based standards has led to the formation of the International Code Council (ICC), composed mainly of model code agency representatives. Current ICC initiatives include an effort to develop a performance-based building code (Weber 1998).

International Energy Conservation Code (1998)

The ICC was formed by the three major model building codes in response to the call for one unifying building code. The move toward a single building code is driven in part by scientific and technological gains that require codes to be constantly updated and modified. The complexity of the current system also requires a constant and time-consuming education and re-education of building professionals. This type of complexity has encouraged an interest from the European community to develop a common standard for building performance across a diverse set of communities. It has also advanced the formulation of the International Energy Conservation Code (IECC) to address a common framework for energy conservation standards.

In 1998, the MEC was re-published as IECC under the auspices of the ICC and began a code update cycle under new ICC code maintenance procedures. The IECC had some major new revisions relative to the previously published edition of the MEC (1995) that include a special table of prescriptive envelope criteria (insulation R-values and fenestration "U-factors") for additions to existing single-family dwellings. Default U-values for windows, glazed doors, and skylights that do not have tested U-values (as determined by the National Fenestration Rating Council) were revised to be consistent with the 1997 ASHRAE Handbook of Fundamentals. Default values in the 1995 MEC were derived from the 1993 ASHRAE Handbook. Compliance with the IECC can be demonstrated using

computer programs, worksheets, compliance manuals, and other enforcement aids that have been developed to assist users of the MEC.

The IECC also permits compliance demonstrations using "systems analyses" (similar to the MEC provisions), which compare the annual energy usage of the proposed structure against that of a reference structure. The rules for the assumptions or standard conditions when performing the analyses have been revised in the IECC to eliminate some of the ambiguities in the MEC and generally bring the IECC more in line with the recommendations of the national energy rating systems guidelines. This performance-based analysis option is helping to bring the model code community closer to the stated goal of one standard.

Utilizing a performance-based format will force the code enforcement, design, and construction communities to evaluate how they do business, and to raise the overall standard for code development (Cantor 1997). The development of one model code will also enhance compliance by reducing the amount of regional variation found in prescriptive standards. Performance-based models require only that the standard be met. Regional variation will be in the design solution and will not be codified by law. This will promote a more regionally based architecture and construction industry, less confusing building codes, and better quality solutions (Quitter 1997).

5 Sustainability and Building Codes

Sustainability became an issue of public concern and international debate during the 1980s. The World Watch Institute measured "progress toward a sustainable society" in its annual State of the World reports (Brown 1984). The U.S. Congress enacted the Food Security Act of 1985 that initiated a program in "Low Input Sustainable Agriculture" to help farmers use resources more efficiently, to protect the environment, and to preserve rural communities. The World Commission on Environment and Development (1987) called for Sustainable Development to "meet the needs of the present generation without compromising the ability of future generations to meet their needs." Numerous books and articles addressed various aspects and implications of sustainability (Brown 1981; Costanza, Daly, and Bartholomew 1991; Young 1990).

According to Charles Kidd (1992), the term sustainability first appeared in print in 1972 in the book titled *Blueprint for Survival*, which was concerned with creating a "sustainable society." The book was critical of the environmental destruction and the "ethos of expansion" in modern industrial societies. But different roots of the term can be found in scientific literature in the fields of biology, ecology, economics, and technology assessment. Rather than those different fields converging on a single definition of sustainability, scholars working in different disciplines have applied different assumptions and methodologies to different problems. Not surprisingly, they have arrived at different conceptions of the term (McIsaac and Brun 1999). Some of this work, such as the biological and ecological analyses of the long-term impact of humans on the biosphere, dates back to the 19th century, and attempted to separate human values from the concept of long-term carrying capacity (McIsaac and Brun 1999).

In the built environment, sustainability and sustainable development is viewed as a strategy by which communities seek to improve the natural environment and the communal quality of life. It has become an important guide to many communities that have discovered that traditional approaches to planning and development are creating, rather than solving, societal and environmental problems. Where traditional approaches can lead to congestion, sprawl, pollution, and resource depletion, the concept of sustainable development offers more lasting solutions that have the ability to strengthen over time.

In "Toward Some Operational Principles of Sustainable Development," Herman Daly (1980) defines the difference between growth and development:

- to grow - to increase naturally in size by the addition of material through assimilation or accretion
- to develop - to expand or reach the potential of; bringing gradually to a fuller, greater, or better state.

He states that "the human economy is a subsystem of a finite global ecosystem which does not grow, even though it does develop ... economic growth cannot sustain itself over long periods of time" (Daly 1980).

Buildings and communal structure are important components in the human evolutionary and domestication process (Wilson 1988). The building professions need to recognize the differences between growth, development, and the stability of a community. These professions can no longer focus only on individual buildings without consideration for the impacts that the construction, destruction, or renovation these buildings have on the environment. The built environment should be viewed in terms of the quantitative (energy, disposal, material cycling, etc.) and qualitative (neighborhood impacts, etc.) impressions that the structures make on the community.

The quantification of building impacts should start with the consequences of the acquisition of resources; the transportation of those resources; the processing of resources into usable materials, products, or equipment; the generation of wastes and toxins in these processes; the transportation of these manufactured goods; the assembly of those components into the building itself, the effect of the building as it sits on and alters the land; the flow of resources through that building during its lifespan, both to maintain the structure and the comfort and services we require, such as water and wastewater, electricity and gas, conditioning the air, etc.; the modifications that might be made to the building during its life; and finally the consequences of the eventual demolition and disposal or reuse of the materials that comprise the building (Eisenberg 1997). Current model code standards exclude almost all of these impacts from their scope of concern.

In the current situation, building codes and regulations influence every stage of the life-cycle process of a building, yet virtually ignore all but one relatively small aspect of that whole process: occupant safety. In focusing narrowly on the safety of people in buildings, to the exclusion of the larger consequences, the process by which codes are created, modified, and enforced lacks a limiting feedback loop to resist higher-impact methods of building (Eisenberg 1997). The incorporation of concepts of sustainable development into the current model code framework is the present challenge.

The Incorporation of Sustainable Concepts

A simplified view of how to incorporate ideas of environmental impact and resource depletion into the model code framework might follow the general rules of the typical building delivery process:

> Planning → Design → Construction → Substantial Completion → Occupancy → Post Occupancy (with some modification).

Planning

During the planning phase, the design professionals set the parameters for the project including the organization of the building design and commissioning team and the responsibilities of each team member. Parameters for discussion will include site appropriateness and impacts of construction, probable building impacts and building performance requirements, future adaptation requirements, and disposal. The parameters set should also include benchmark information that will be used to evaluate the final performance of each system (ASHRAE 1995).

Formulation of Standards. As noted, model building codes summarily ignore resource conservation issues and more importantly remain beyond consideration in the processes by which codes are written, modified, and enforced. Yet buildings account for one fourth of the world's wood harvest, two fifths of its material and energy usage, and one sixth of its fresh water usage. In the past 100 years, the level of carbon dioxide in the atmosphere has risen 27 percent, one quarter of which has come from burning fossil fuels just to provide energy for buildings. During the same period, the world has lost 20 percent of its forests. This is at a point when only 2 billion of the nearly 6 billion people on the planet live and work in modern resource-intensive buildings.

Apply the level of resource intensity that is required by our modern building codes to the total world population and it becomes immediately apparent that we do not have the resources to house everyone at the level we have established as the minimum standard for decent housing. Yet we are in the process of developing building codes (ICC) based on our resource intensive way of building and promoting those codes worldwide (Eisenberg 1997).

Formulation of energy performance standards for buildings is a critical issue in balancing the resources with demand. Both prediction and monitored performance standards have been formulated. Predicted performance standards simulate the performance of the structure against a referenced target and have been

used successfully in energy conservation and life cycle analysis. Two current models are available or will soon be available. Both have been developed in conjunction with the U.S. Environmental Protection Agency (USEPA). The first is a qualitative model; the Environmental Knowledge Base Advisor for Facility Life-Cycle Decisions (EnvKB). The second model is more quantitative in nature and will be available shortly in alpha test mode. It is the Building for Environmental and Economic Sustainability (BEES) model developed by NIST. Monitored performance standard involves the monitoring of the actual building performance data and applying the results against targeted references. The need to specify realistic target figures is important in both cases. Tying both approaches with the current distribution of energy consumption patterns has been suggested. Provided that the method of predicting energy use has been validated, that targets have been set at realistic levels, and that the current distribution of energy consumption in the building sector is known, then it should be a relatively straightforward task to quantify, with some precision, the potential savings that would accrue from building energy performance standards.

Design Phase

The design phase outlines the impact and energy requirements for each building system. These requirements typically include:

- design criteria and assumptions
- descriptions of each system
- the intended operation and performance of each system
- the commissioning plan
- documentation requirements
- verification requirements
- maintenance requirements
- disposal and re-use (ASHRAE 1996).

Construction Materials. Procurement, production, and transportation of building materials have significant impacts on the environment, and involve high energy costs. For example, selecting local materials helps strengthen the local economy, as well as eliminating the need for transporting materials over large distances, which in turn reduces pollution, fuel consumption, and other transportation-related environmental impacts. Some materials have more of an impact on the environment than others. Industrialized society's voracious consumption of virgin and synthetic material resources such as timber, minerals, metals, plastics, glass, and concrete increasingly depletes our ecosystems' natural capital and produces enormous amounts of waste and pollution. Residents of the industrialized nations comprise only 20 percent of the world's population, yet consume 86

percent of the world's aluminum, 81 percent of its paper, 80 percent of its iron and steel, and 76 percent of its timber (Roodman and Lenssen 1995).

Virgin materials have higher levels of embodied energy (energy required to harvest, manufacture, and transport the materials) than recycled materials. For these reasons, the use of recycled materials can both conserve natural resources and reduce energy production costs. The use of alternative building materials can also conserve resources, as can the use of technologies that allow more efficient use of lumber, such as: stress-skin panels; engineered framing products, such as I-beams, glue-laminated products, and finger-jointed lumber. These products allow for the use of "scrap" and small-dimension lumber that might otherwise be landfilled.

For example, some activities that might help conserve energy and environment are: (1) using lumber that comes from ecologically-managed forests, (2) choosing materials that require low amounts of energy to get from raw material to delivered product (low embodied energy), (3) avoiding materials that are toxic (during production and use) to people and the environment, (4) selecting products that are engineered to save raw materials, (5) choosing products made of recycled and recyclable materials, and (6) using locally-produced materials.

Many building products available today are manufactured from recycled materials, and can substantially reduce the embodied energy costs. For example, organic asphalt shingles contain recycled paper, and some shingles are made from re-manufactured wood fiber. Cellulose insulation is manufactured from recycled newspaper. Although building codes allow the usage of alternative and recycled materials, there are no enforced standards on the mandatory usage of these materials to promote and conserve energy. Mandatory standards on the proportion of recycled materials to be used for construction of buildings could help reverse the trend of using energy-inefficient, environmentally unfriendly materials.

Construction Phase

During the construction phase of the process, building systems are installed in conformance with the contract documents and the commissioning plan. In a typical phase of construction, shop drawings and operation and maintenance manuals are submitted, reviewed, and documented before installation of each system or subsystem (ASHRAE 1995).

Over the years, research has led to innovations that have dramatically reduced both the energy demand of buildings and the magnitude of internal energy-consuming interactions within them. Equally important has been the research

and years of experience that now enable designers to select materials and design building envelopes, windows, and interiors that respond naturally to meet the comfort requirements of their occupants instead of accomplishing energy efficiency by forcing an efficient result through the mere use of electrical, mechanical systems, and central management systems. The latter should be used under backup conditions only when necessary, over a much reduced range of demand, for less frequent or shorter times. If this approach to building codes is adapted, the results automatically optimize a building's energy consumption.

Building envelope requirements should be determined by a combined form of performance and prescriptive standards. Provisions should be made to substitute alternate envelope systems and materials that can meet the same standards as traditional components. A component/performance-based approach would work from a micro- to a macro-level by specifying materials that comprise the end structure, instead of specifying the qualities of the end structure in isolation. This does not necessarily mean that codes should state specifications for each and every material, but it does suggest that requirements for each component of the building should be set independently. A cumulative standard for the whole building should also be set so that a shortfall in any single system will not dramatically impact the overall energy performance of the building system.

Waste. Construction wastes account for one-fourth of total landfilled waste in the United States. Yet many construction materials can be recycled, including glass, aluminum, carpet, steel, brick, and gypsum. Construction and renovation waste can also be reduced by salvaging, rather than landfilling, items that have some remaining life, such as appliances, household goods, office equipment and furniture, and building materials. Source reduction is the first step to a successful waste reduction program. Source reduction involves taking primary actions to eliminate or reduce the amount or toxicity of materials before they enter the municipal solid waste stream. According to the California Integrated Waste Management Statute of 1993, Source Reduction includes the following actions (DOE 1999):

- reducing the use of nonrecyclable materials
- replacing disposable materials and products with reusable materials and products
- reducing packaging
- reducing the amount of yard wastes generated
- establishing garbage rate structures with incentives to reduce the amount of wastes that generators produce
- increasing the efficiency of the use of paper, cardboard, glass, metal, plastic, and other materials.

Code Enforcement

The implementation of performance or combined prescriptive/performance standards, requires greater technical skills for enforcement officials. The education of code officials and enforcement personnel is key to the implementation of sustainable issues in the model code framework. In a recent study by the Building Standards and Guidelines Program, local code officials from various jurisdictions in 13 States were interviewed. The interviews focused on the code officials' awareness of the residential building energy code in States that had adopted the Model Energy Code (MEC). Results of the survey include:

- In general, the code officials' basic awareness of the residential building energy code was good; about 94 percent of the code officials interviewed knew about the new State code. Even though awareness of the code was good, only 41 percent of code officials felt that their colleagues had at least a good understanding of the code; 25 percent felt that their group had a poor or extremely poor understanding. Code officials also felt that about two-thirds of builders and subcontractors had a poor or extremely poor understanding of the code and that this lack of understanding by the building community was the primary obstacle to residential building energy code compliance.
- The second most significant obstacle was code complexity and lack of simple tools to verify compliance. Lack of support materials and technical support were rated next in importance. Lack of funding and staff were rated relatively low as obstacles to effective compliance and enforcement. Other studies also suggested that these obstacles to energy code enforcement and compliance were not unique to energy codes, but that the nature of energy codes aggravated them.
- The most frequently mentioned way that code enforcement could be improved was to increase the training of code officials. Simplification of codes and compliance tools were also frequently mentioned. Training and providing materials to building professionals and the public on codes and on their benefits were the fourth most frequently mentioned approaches for improving code enforcement.
- Almost three-fourths of building code officials reported that they used a code manual to obtain information on the residential building energy code. About 22 percent of those interviewed said that they used MECcheck or other software, worksheets, etc., to assess code compliance. About one-fourth of the code officials relied on other codes or information from code organizations, the State, and the building or product industries, or training and seminars for knowledge about a specific code.

- The organizations they relied on primarily for assistance were State agencies, model code groups, and building trade associations. Only 11 percent reported that they received technical assistance from the Department of Energy (DOE) or the Pacific Northwest National Laboratory (PNNL). Although the share of interviewees reporting assistance from DOE or PNNL was relatively small, it probably reflected the fact that DOE and PNNL efforts have been directed largely at the State level, model code groups, and the building industry. Local officials were probably unaware of these efforts. Because code officials turned to the State, model code groups, and building trade associations for assistance, DOE and PNNL efforts were probably reaching local code officials, although indirectly.
- Feedback on MECcheck was a useful indicator of the effectiveness of DOE and PNNL efforts. Over half of the code officials interviewed said that they had heard of MECcheck and nearly half reported using it. MECcheck was the second most common source of information about the residential building energy code. MECcheck has made inroads into the building professions also. (About 27 percent of the builders reported to be using it.) It appeared that it also was becoming a tool for more widespread use, with subcontractors and even lumberyards using it. In some jurisdictions, builders were commonly using MECcheck to indicate code compliance. One potential limiting factor, particularly for code officials, was a shortage of computers. In Indiana, nearly one third of the officials said they have no computers in their office.

Substantial Completion

"Substantial completion" is also sometimes referred to as the acceptance phase. This is the point when pre-start-up inspections are performed. This includes verifying that the components were installed as intended and that the intended performance criteria were followed. Acceptance procedures include: functional performance tests, verification and documentation corrective measures (if necessary), inter-systems performance testing, and acceptance (ASHRAE 1995).

Training: The time dedicated to the training of operational personnel depends on the complexity of the building system. Complex systems may require a more rigorous training regime. Operator participation of the initial verification and testing phase is an important part of the training strategy. Instruction is provided by several different sources: the design professional, equipment manufacturers, controls contractor, testing contractor, and other specialty contractors.

Building Occupancy

A conventional building constantly interacts through its outer "envelope," windows, and ventilation system with the ever-changing outside world. The portions of the ambient temperature, fresh air, and lighting needs of the occupants that are not provided by the building's natural response system are supplied by energy-driven thermal, ventilation, and lighting systems. A building therefore is a "whole" physical object, and behaves as a whole dynamic system.

The productivity of occupants, which defines a building's economic value to the owners, is not determined merely by thermal comfort or sufficient lighting. It is increasingly understood that the quality of the space enhances its economic value. It is becoming clear that the perceived quality of the space derives from the user's ability to have control over comfort and lighting conditions. Thus one of the great gifts of energy-efficient and climate-responsive buildings is that the very design practices create conditions that improve the quality of the space and the performance or productivity of the occupants.

Over the years, research has led to innovations that have dramatically reduced both the energy demand of buildings and the magnitude of internal energy consuming interactions within them. Equally important has been the research and years of experience that now enable designers to select materials and design building envelopes, windows, and interiors that respond naturally to meet the comfort requirements of their occupants instead of accomplishing energy efficiency by forcing an efficient result through the mere use of electrical, mechanical, and central management systems. The latter should be used as backup systems (only when necessary), as little as possible, or for less frequent and shorter periods of time.

Post Occupancy

Operations or post-acceptance commissioning is a critical step for effective and on-going functioning of a building. Buildings are dynamic structures. As the occupancy and use requirements of a building change, the building systems need to be adapted. The history of the modifications and changes to the facility must be carefully monitored and documented, and the commissioning procedures and testing of the facility must also be continually updated. Systems should also be re-tested periodically to measure and verify actual performance.

Operation and Maintenance

It should be possible to maintain "new building" performance during the building's whole design life. A trade off between initial building cost and the operational cost is increasingly inevitable to meet the life cycle energy requirements of buildings. The experience from Michigan (DOE 1999) indicates that MEC raises home buyers' first costs a little, but it lowers operating costs a lot. DOE studies conducted at Pacific Northwest National Laboratories indicate that complying with the MEC would increase the initial first-cost of the typical single-family home in Michigan by about $1400, compared to complying with the older Michigan code. However the net savings in energy is expected to be about $90 a year.

When evaluated over a 30-year period, the initial costs associated with designing and constructing a building represent less than 2 percent of the overall life-cycle costs. The cost of operating and maintaining a building represent approximately 6 percent of the total cost. In comparison, the majority expenditure, representing 92 percent of the life-cycle costs, is for the personnel costs of building occupants (DOE 1999).

This distribution of life-cycle costs suggests that sound financial planning for buildings should become more balanced between first costs associated with constructing a building, the ongoing costs associated with operations and maintenance, and the design factors affecting the health and productivity of its occupants. Conventional financial analysis methods are not well adapted to accounting for such life cycle costs in all three areas. It often is difficult to also integrate these three separate corporate functional areas to make overall optimal life-cycle based decisions and effective first cost tradeoffs. Building Futures advocates a modified approach to the conventional—that which is life-cycle based.

There is a growing interest in the operation of buildings and resulting utility costs. This attains significance in the case of consumers of housing and commercial building market, may not really build, but occupy the buildings. Many tools are being developed and promoted to monitor and control operational costs. The question is whether building codes can help people out of this "problem curing approach" to a "problem prevention" approach.

Many codes address energy related aspects of design, but do not explicitly address life cycle issues. It should be understood that a properly insulated house is not necessarily energy conserving. Many externalities affect the energy consumption of the buildings, e.g., the selection and installation of various mechanical and electrical systems, or consumption patterns of the inhabitants.

Building codes should reflect a combination of prescriptive and performance standards to control the maintenance and operation of buildings. This will not only reduce the energy consumption, but also protect the inhabitant from high life cycle costs. This approach will also disable people from using bad quality materials that do not last long and need excessive maintenance resulting in higher energy consumption and costs. Prescriptive standards will especially be essential to meet the life cycle requirements of materials and elements that are not accessible or replaceable. For example, plastics that are often used for joining and sealing are "built-in" and are not accessible after a building is ready for occupancy.

An annual energy analysis should be made mandatory regardless of the approach taken for design. MEC requires this only for its design by systems analysis approach.

Quantifying and standardizing the life cycle costs may not be possible through building codes since building economics are variable. Moreover, economics is a societal issue that has more to do with management than with building codes, and should be left to the marketplace to determine. However, the very nature of performance approach allows flexibility, and enables builders to decide whether the operational costs of buildings be optimized even further than would be advocated by the code. In many instances, this is determined by using better materials and obviously higher initial cost. This tradeoff must be left to the individual builder, who in any case is not allowed to cross the standard set by the codes, that are optimum and ideal. In a society like that in the United States, unlike in European countries where taxation is used as a means to restrict usage of certain commodities, it would be more important to set standards that respond to the energy reduction patterns than to bother about ones life cycle costs.

However, it would be more useful to quantify the building energy standards into real energy units to make practical monitoring during operation possible, instead of leaving the energy calculations at the project approval level. Life cycle costs should be monitored using software developed for that purpose. This will not only enable people to monitor their energy consumption patterns, but also to upgrade when some new material, component, or system comes into the market that performs better than those in current construction. The latter part especially becomes difficult through building codes since construction research is advancing rapidly and new alternatives are coming up within short periods of time.

Human Behavior

Even with strict regulatory compliance during the construction or remodeling of a building, energy consumption patterns can still vary extensively between similar structures. Energy consumption in almost identical residential structures was found to vary significantly depending on the composition of the household and their habits, even within a fairly small differential in indoor temperatures (ASHRAE 1995). This suggests a nonlinear relationship between indoor temperature and heating consumption, with perhaps a much stronger relationship between occupant behavior and consumption than with construction codes and consumption. The economical value of occupant behavior in energy conservation relative to alternatives of increased insulation values, reduced temperatures, or building envelope improvements, needs to be assessed. The inclusion of performance-based codes can help to address some of the differences in occupant-based impacts.

6 Conclusion

The design, construction, and maintenance of buildings has a tremendous impact on our environment and our natural resources. There are more than 76 million residential buildings and nearly 5 million commercial buildings in the United States today. These buildings together use one-third of all the energy and two-thirds of all electricity consumed in the United States. Another 38 million buildings are expected to be constructed by the year 2010 (DOE 1999). The challenge will be to build them intelligently, so that these buildings use a minimum of nonrenewable energy, produce a minimum of pollution, and cost a minimum of energy dollars, while increasing the comfort, health, and safety of the people who live and work in them. Although laden with politics and normative bias, the incorporation of energy and environmentally related standards into the current patchwork of code and code enforcement policies may be the most effective way of accomplishing building energy and resource efficiencies in the private building sector.

This report has attempted to outline the current status of national building codes and standards in terms of how they address energy conservation and the environmental impacts of our built facilities. Generally, the model codes and standards take a narrow view of public safety and focus almost entirely on prescribed structural conformance and life safety components of a building design. These are important criteria to consider. Equally important, however, are the long-term impacts of buildings and building construction that are noticeably absent from the current model code literature.

This study recommends a stronger performance-based approach to establishing code requirements. This approach directs only that the end product perform according to the desired criteria; the means to achieve that end need not be explicit. The International Code Council (ICC), formed by the three major model building codes to facilitate the unification of the model codes also proposes a performance-based approach (Weber 1998). The argument for a performance-based approach to establishing code requirements is supported by the following rationale. Using a performance-based format will raise the overall standard for code development. Performance-based models will encourage more regionally based design and construction solutions, will be less confusing, and will promote better quality solutions.

The quantification of building impacts should start with the consequences of the acquisition of resources: (1) define the impacts of the components used to construct the facility, (2) quantify the flow of resources and the impact of services that flow through that building during its lifetime, and (3) quantify the consequences of the eventual demolition and disposal (or reuse) of the structure. Unfortunately, current model code standards exclude almost all of these impacts from their scope of concern. Currently, building codes and standards influence every stage of the life-cycle process of a building, yet ignore all but occupant safety. In focusing narrowly on the safety of people in buildings to the exclusion of other consequences, the process by which codes are created, modified, and enforced lacks a limiting feedback loop to resist higher-impact methods of building (Eisenberg 1997).

The incorporation of concepts of sustainable development into the current model code framework can positively impact all phases of the building delivery process, from pre-planning to post occupancy and disposal. The present challenge is to effectively evaluate these impacts, and to develop performance-based criteria that can effectively describe the needs of the user and the expectations of the facility.

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Appendix: Environmental Impacts Relating to Specific Materials

As a part of this research environmental impacts relating to specific materials were developed. Although not part of the original scope of this study, they are presented here as an appendix to the original work (AIA 1996).

Aluminum

Environmental Issues

Bauxite strip mining causes some loss of tropical forest. Reclamation may reduce long-term effects on ecosystem, but some species will be lost. Bauxite comprises about 8 percent of the earth's crust, but is a finite resource.

Energy Consumption

The embodied energy of aluminum is very high, but comparing it with the embodied energy of alternative materials may be misleading. Aluminum is very lightweight, and pound-for-pound comparisons may show aluminum in a bad light. The aluminum industry accounts for 1.4 percent of the annual world energy consumption. Embodied energy at the point of use for 1 lb of aluminum produced from bauxite is 103,500 Btu. Aluminum produced from recovered scrap and recycled aluminum rather than bauxite ore saves about 80 percent of total energy consumption.

Waste Generation

Bauxite refining yields large volumes of mud containing trace amounts of hazardous waste. For every pound of aluminum, 0.02 lb of spent potliner, a hazardous waste, are generated in the manufacturing stage. Most airborne emissions are recovered, but a small amount of carcinogenic hydrocarbons escape incineration. Fabrication and finishing may produce heavy metal sludges and large amounts of waste waters requiring treatment of toxic chemicals. Anodizing and powdered coatings may be the most environmentally friendly finishes.

Suggestions for Efficient Usage

It would be useful to use or specify aluminum products fully or partially made from recycled scrap (many alloys cannot be made from 100 percent recycled scrap). Designs that will facilitate recycling of aluminum later should be encouraged. Using mixed-material assemblies shall be avoided. It may also be useful to consider less energy-consuming alternative materials in applications where the advantageous characteristics of aluminum are not needed.

Concrete

Environmental Issues

Environmental concerns arise from all phases of concrete's life cycle. They include land and habitat loss from mining activities, air and water quality degradation from materials acquisition and manufacture, and land use for disposal of waste materials and demolition debris. The principal risks to water quality result from improper disposal of rinse water from mining, manufacture, and fabrication.

Waste

One of the major environmental concerns in the use of concrete is the disposal of demolition debris from structures. Concrete may account for over 67 percent of the weight and 53 percent of the volume of demolition wastes in North America. State of the art technology and improved management practices have enabled industry in the United States to reduce manufacturing waste by over 90 percent in the last 20 years. Little has been done, however, to recycle concrete from demolished structures and reduce the amount of concrete rubble that goes into the solid waste stream.

Energy Consumption

Concrete is used extensively as a thermal mass in walls and floors for passive solar design, but is extremely energy intensive to produce.

Air Quality

The principal risks to air quality result from dust emissions (particulates) in nearly all phases of manufacture, transportation, and use. Emissions of combustion gases from coal or gas fired kilns may include CO_2 and SO_2 as well as par-

tially combusted organic materials. The binding agent for concrete, cement, is made by the operation of a high temperature kiln. In the United States, 9.8 million metric tons of CO_2 were emitted in 1987 as a result of the operation of these kilns to manufacture about 76 million metric tons of finished concrete. Concrete is stable and has minimal indoor air impacts. It can be cleaned with water and needs very little or no finish as a floor system.

Suggestions for Efficient Usage

It would be useful to minimize off-cutting by careful and precise dimensioning of materials. Use of more energy efficient materials, such as higher insulation value concrete should be encouraged. Codes should require a waste management plan from the contractor that incorporates waste minimization and pollution prevention actions, such as preventing run-off from wetting of concrete for curing, minimizing water used to wash equipment, returning excess concrete to vendors for re-mixing, using waxes or synthetic non-stick treatments for forms. This will help in effective and efficient utilization of the positive aspects of concrete such as fire resistance, thermal mass, and longevity.

Steel

Environmental Issues

Construction materials are the single largest use category for steel, accounting for over 11 million of the 84 million tons of steel products shipped in 1989 in the United States. The major environmental concerns include energy, resource use, land and habitat loss from mining activities, and air and water quality degradation as a result of mining and manufacturing activities. The principal risks to air quality include dust and combustion emissions from ore refinement, combustion emissions from blast furnace operation for the production of raw iron, and basic oxygen furnace (BOF) emissions from the production of steel. The major risks to water quality result from improper disposal of procession waters from mining and milling operations. Steel is considered to be the most recyclable building material since it can be easily separated from the waste stream magnetically and reprocessed into a high-quality product. Recycled steel accounts for almost two-thirds of new steel shipped in the United States. Reuse of steel and iron in manufacturing provides a substantial savings in energy and raw materials over the use of equivalent amounts of raw iron ore.

Energy Consumption

Total embodied energy is estimated at 19,200 Btu per pound of product.

Trends

The use of recycled steel and iron for the production of new steel continues to increase relative to the use of ore in the United States. Older, more polluting, and less energy-efficient refinement processes such as the open hearth furnace have been abandoned in this country, and advances in emission control technology have made steel-making a much cleaner process than a decade or two ago. Pollution from this process has been reduced by about 90 percent over the last decade.

Suggestions for Efficient Usage

Because many steel products are made totally or partially from recycled steel, steel may be considered to be less environmentally harmful than many other alternatives. Current codes deal with buildings in isolation. Due to their performance nature, building codes would not restrict materials that involve high energy costs mentioned above. Codes should also feature issues relating to the environmental impact of the buildings. This is where the prescriptive component of the codes should impose restrictions. Also, standards on total energy consumption of the materials used for construction can address this issue. A pragmatic standard can be formulated by comparing the total energy consumed for materials, on average, per building and the amount of energy available for the same. Such a calculation would simply divide the total energy available for production and transportation of materials by the total number of houses being built. The difference would need to be met by alternative, recycled, and renewable energy sources. This is similar to the provisions made in the systems analysis section of MEC where annual energy analysis excludes energy used from renewable sources.

Glass

Waste and Environmental Issues

Mining of glass sand, limestone, and soda ash result in particulate emissions, soil erosion, habitat alteration, pollutant runoff, and air pollution associated with energy consumption for mining, processing, and transporting materials. Glass manufacturing can release air pollutants and water pollutants that con-

tribute to numerous environmental problems. Scrap glass, or "cullet," is generally recycled back into the glass-making process. Glass building products removed during remodeling or demolition are usually disposed of in landfills.

Natural Resource Depletion

Glass sand, limestone, and soda ash are finite resources, but supplies are adequate to meet future demands.

Energy Consumption

The energy currently embodied in fiat glass has been estimated to be 13.5 to 15 million Btus (15,825 MJ) per ton. However, improvements in energy efficiency in glass making indicate that energy savings of approximately 30 percent are possible through currently available technology. Advanced technologies now under development could result in energy savings of up to 65 percent.

Indoor Air Quality

Glass is inert and has virtually no impact on indoor air quality, although assemblies of glazing systems can cause drafts and unwanted infiltration.

Suggestions for Efficient Usage

As a result of recent technological improvements in the thermal efficiency of glass, some glasses offer increased day lighting without sacrificing energy efficiency. Usage of such glasses and low-E or aerogel glass units to improve the insulating qualities of glass building products should be encouraged. Consider plasma glass, currently under development, to improve energy efficiency in cold climates. When charged with electricity, the plasma glass unit emits incandescent light and about 500 watts of heat—generally enough to heat a room. One could specify that contractors attempt to salvage and reuse glass building products removed during construction, repair, and remodeling.

Insulation

Waste and Environmental Issues

The fully halogenated chlorofluorocarbons (CFCs) that are used as blowing or expansion agents in polymeric plastic foam insulation materials have been found

to cause damage to stratospheric ozone, which has been linked to increased incidence of cataracts, skin cancer, and depression of the human immune system.

Energy

The energy-conserving properties of thermal insulation offer significant environmental benefits. Energy required to produce insulation varies depending on product used; data are not yet available in a form that is appropriate for comparison.

Indoor Air Quality

Concerns associated with insulation include the release of fibers and/or volatile organic compounds during installation or use. There are environmental concerns related to asbestos insulation that may arise during renovations and demolitions. The USEPA's National Emissions Standards for Hazardous Air Pollutants (NESHAP) has a detailed appraisal of this issue.

Suggestions for Efficient Usage

Building codes may be designed to restrict the type of blowing or foaming agent used in rigid or blown foam insulation that has hazardous effects, and to encourage the use of materials that contain alternatives to CFCs. While HCFCs may currently be used as alternatives to CFCs, there is some concern that HCFCs may pose other environmental problems. As alternatives to HCFCs are developed, materials that use these alternatives should be explored. Codes should specify sufficient insulation for the climate zone in which the building is located to save energy over the entire life of the building. Codes should specify installation techniques to keep insulation dry to prevent growth of fungi and bacteria. Such codes should require adequate ventilation during installation and curing.

Ceiling Tiles

Waste and Environmental Issues

The major environmental concerns associated with mining the raw materials include energy and resource use; soil erosion, pollutant runoff, land and habitat loss; and air and water degradation. The principal risks to air quality include particulates, dust, and combustion emissions from mineral and ore refinement, in addition to combustion emissions from furnace operation for the production of coke, mineral wool, steel, and aluminum. The major risks to water quality result

from mine runoff and polluted wastewater generated during coking, steelmaking, galvanizing, and aluminum production. Few wastes are generated during the manufacture of ceiling panels and tiles. The solid wastes that are generated during fabrication of panels, tiles, and suspension systems are recycled back into the processes. Manufacture of panels and tiles reduces wastes from other sources, specifically slag from steel production and recycled newsprint.

Natural Resource Depletion

Coke, steel, and aluminum production consumes significant amounts of water. Several raw materials used in making steel for suspension systems—nickel, chromium, and manganese—are in very limited supply in the United States. However, over the past 10 years, recycling of scrap steel into steel production has resulted in 1.2 trillion lb of steel being reused here and abroad. Bauxite strip mining causes some loss of tropical forest and habitat.

Energy Consumption

Use of recycled paper in production of ceiling panels and tiles requires approximately 27 to 44 percent less energy than use of virgin wood. The total embodied energy of steel suspension systems per pound of product is estimated at 19,200 Btus. Production of steel from scrap requires approximately 39 percent of the energy required for the production of steel from raw materials using the basic oxygen furnace process. The embodied energy for aluminum suspension systems is very high: 103,500 Btus per pound of product at the point of use.

Indoor Air Quality

Ceiling panels and tiles may act as sinks. Some studies indicate that ceiling panels and tiles adsorb and desorb certain VOCs at significantly higher rates than carpet and pillow; other studies report no major emissions or emissions below allowable limits.

Suggestions for Efficient Usage

Codes shall specify durable ceiling panels and tiles that can be reused and repainted, and suspension systems that are made totally or partially from recycled material. Codes should require the reuse of suspension systems during remodeling. Separate waste during demolition and recycle should be made mandatory.

Tropical Woods

Natural Resource Depletion

At the present rate of deforestation, tropical forests will be gone by the middle of the next century. Sustainable yield management of tropical forests is the solution, but presently less than 1 percent of natural primary forest is managed under sustainable yield principles. Some popular tree species may become endangered due to over exploitation. For sustainable forest management to become a success and to relieve the pressure on some popular species, the trade in lesser-known species must be encouraged.

Waste Generation

Scientists believe that, for every cubic meter of wood extracted in forestry operations in Southeast Asia, 1 m^3 of wood debris is left behind and an additional 0.25 m^3 of wood is lost in processing.

Indoor Air Quality

Wood finishes emit volatile organic compounds during application and curing that lead to ground-level ozone formation. Some of these finishes will have to be reformulated to comply with new, lower emission levels resulting from the enactment of the Clean Air Act Amendments of 1990. Small woodworking shops often vent their emissions directly to the outside. Wood products naturally emit small amounts of organic compounds such as aldehydes. Some adhesives for laminates and finish coatings on furniture, cabinetry, and flooring contain formaldehyde and other VOCs. (See the ERG particleboard and plywood reports for more information on formaldehyde.)

Suggestions for Efficient Usage

Codes shall explore alternatives to woods in construction and specify woods produced from sustainable management or lesser-known species. Many species that are alternatives to endangered species listed by WARP and CITES (organizations that provide information on various wood products). Codes should also regulate the production and construction processes to reduce environmental impacts, e.g., by requiring builders to provide adequate ventilation when applying finishes.

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14. ABSTRACT

The building construction industry consumes a large share of the (often virgin) building materials produced. Most building energy and energy-related expenditures are applied to privately owned properties. Attempts to minimize building energy expenditures and their co-incidental environmental impacts must therefore focus on the private sector and on regulation mechanisms currently in place.

The principal vehicle for the regulation of private building and construction practices is building codes and standards, which primarily work to ensure public health and safety. Today's "system" of codes and regulations is a patchwork developed and enforced by many agencies, none of which are focused on the conservation of energy or natural resources. What is needed is a general set of codes that also focus on life cycle costs of structures as those costs relate to energy use and the environment. This study summarizes the current status of national building codes and standards relative to energy efficiency and environmental competency. It also identifies ways in which those codes and standards could be changed to reduce energy consumption and negative effects on the environment.

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